Sugarcane Chopper Harvester Extractor Fan and Ground Speed Effects on Yield and Quality

R. P. Viator, E. P. Richard, B. J. Viator, W. Jackson, H. L. Waguespack, H. S. Birkett

Abstract. *Operational settings on chopper harvesters are extremely important in green-cane harvesting since one is relying solely on the harvester to remove extraneous matter instead of the traditional pre-harvest burn method. The objective of this research was to determine the combined effect of selected ground and fan speeds on sugar yield, cane quality, and field losses using a commercial chopper harvester. In both 2003 and 2004, a split-plot experiment was performed at harvest with the main plots having ground speeds of 4.0, 4.8, and 5.6 km h^{-1} and subplots having primary extractor fan speeds of 650, 850, and 1050 rpm of the 1.5-m diameter fan. Under the optimal conditions (low leaf and soil moisture), the 1050 rpm fan speed increased theoretical recoverable sugar (TRS) by 10% but decreased cane yield by 15% compared to the two lower fan speeds resulting in similar sugar yields for all fan settings. Under poor conditions (high leaf and soil moisture), the 1050-rpm fan speed decreased cane yield by 13% without an increase in TRS, resulting in lower sugar yields than the low or medium fan settings. Ground speed, under both conditions, did not affect cane yield or quality. The chopper harvester performed well under ideal conditions with a primary fan speed of 1050 rpm but had decreasing performance under poor conditions regardless of fan speed.*

Keywords. *Sugarcane, Chopper harvester, Green-cane harvesting, Mechanical harvest.*

Sugar industries throughout the world are rapidly adopting green-cane harvesting (GCH) mainly due to public pressure to reduce standing burns and the potential for increased sugar recovery with this system (Richard et al., 1996). Cane loss and extraneous matter (EM) are higher with GCH especially under poor harvesting conditions, which would include high leaf and soil moisture or severely lodged cane (Whiteing et al., 2001). Because with green-cane harvesting one is relying solely on the harvester to remove EM instead of the traditional method of burning the standing cane before harvest, careful consideration must be given to ground speed and primary extractor fan settings.

To optimize yields, a balance between EM removal and cane loss must be achieved. Increasing primary extractor fan settings can reduce EM, but excessive fan speeds can also remove mature billets (Richard et al., 2001). Results in Australia from Shaw and Brotherton (1992) indicate that a 1% reduction in EM resulted in a 4.2-Mg ha^{-1} cane loss; often when fan speed is increased to remove leafy material, billet pieces are also removed. Legendre (1991) reported that older varieties in Louisiana showed 1.4- to 2.6-g kg^{-1} sugar reduction with each 1% increase in EM. High EM levels negatively affect harvester throughput, load density, and transport cost (Richard et al., 2001). Increased fiber reduces mill throughput, extraction rates, juice quality, and quantity of recoverable sugar (Meyer et al., 2004), and increases mill maintenance costs (Legendre and Irvin, 1973; de Beer, 1980; Rozeff and Crawford, 1980; de Beer et al., 1983; Dick, 1986; Anon., 1988; Ueno and Izumi, 1992; de Beer et al., 1995). Rein (2004) stated that more trash due to GCH results in more sugar losses in bagasse, degradation of sugar color, higher starch levels in juice, and higher milling costs with lower revenue. Some industries that are production and process integrated have incorporated this concept of economically recoverable sugar; they are now planting varieties that are not necessarily the highest yielding but the most profitable (Cock et al., 2000).

The objective of past and present harvesting systems should be to deliver the maximum quantity of cane with the highest sugar quality in the most efficient manor (Richard et al., 1996). Similar to the whole-stalk harvesting system, where quality was sometimes sacrificed for increased productivity at decreased cost (Richard et al., 1996), chopper harvesters are often used to maximize quantity without regard to quality. Increases in theoretical recoverable sugar (TRS) from improved varieties have not been accompanied by improved harvesting practices (Romero et al., 1996).

Research has been conducted on harvester efficiency and continues as new improvements are made to mechanical harvesters. Whiteing et al. (2001) reported that the older model harvesters were limited in the ability to remove EM at high pour rates, without increasing cane loss. Scandaliaris et al. (2004) reported cane losses of 3.6% to 5.8% with a new model harvester compared to 4.8% to 7.7% with the older model harvester at a 1000 rpm fan setting. The test machine incorporates a number of new design features relative to the

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superseded CAMECO CH2500 model, the performance of which has been reviewed by a number of researchers. A number of the features in the new machine were reportedly incorporated with the goal of enhancing the performance of the machine in green cane. It was therefore considered appropriate to benchmark the performance of the new machine under local conditions.

Another variable impacting harvester efficiency is the quality of the sugarcane crop. The major variety planted on 90% of the Louisiana acreage, LCP 85-384, has a small stalk diameter and tight leaf sheath that makes EM removal difficult during harvesting (Milligan et al., 1994; Richard et al., 2001). The objective of this research was to determine the combined effect of selected ground and fan speeds on sugar yield, cane quality, and field losses in LCP 85-384 using the test machine.

Materials and Methods

Based on information from a representative sample of growers harvesting with the CAMECO CH3500 (table 1), ground speeds of 4.0, 4.8, and 5.6 km h^{-1} (indicative of pour rates of 67, 80, and 91 Mg h^{-1}) were selected as main plot treatments and main extractor fan speeds of 650, 850, and 1050 rpm as split-plot treatments. Split plots were three 1.8-m rows that were 46 m long.

Treatments were replicated four times in a RCBD in fields of first stubble LCP 85-384. Cane yield was determined using a modified billet wagon equipped with electronic load cells. TRS level was assessed from a randomly collected billet sample (Johnson and Richard, 2003) from each plot using the core press method (Birkett 1977, 1998; Chen and Chou, 1993). Cane loss from the cleaning system was determined by collecting the residue that was ejected from the harvester. In 2003, these samples were collected from three 1.0-m^2 sections directly from the field surface. In 2004, matter extracted from the harvester was collected using nine 0.3-m^2 rectangular screens positioned on the field surface. The residue samples were analyzed by direct cane analysis to determine the residue composition, which was then used to predict the TRS using the standard core-press method formula (Birkett 1977, 1998).

Table 1. Grower survey results.

	Forward Speed (km h^{-1})			Extractor (rpm)		
Grower	Slowest	Fastest	Average	Lowest	Highest	Average
A	4.8	6.0	5.4			1060
B						900
C	5.6	6.4	6.0	850	950	900
D	4.8	5.6	5.2	850	900	875
E	5.6	6.4	6.0	800	850	825
F	4.8	5.6	5.2			1000
G			2.5			960
H	4.0	4.8	2.8	800	1000	900
I	5.6	6.4	6.0	850	950	900
J						1000
K	4.3	4.8	4.6	850	900	875
L	5.1	6.4	5.8	900	950	925
M	5.6	7.2	6.4	650	650	650
Average	5.0	6.0	5.1	819	894	905
Median	5.0	6.2	5.4	850	925	900
Mode	5.6	6.4	5.2	850	950	900

In addition to harvester data, hand-cut whole-stalk samples (10 stalks/sample) were collected at random from each replicate to determine extraneous matter removal efficiency (EMRE). Mason et al. (1980) defined EMRE as the portion of EM in the field that is removed by the harvester. All non-stalk material and soft/immature cane joints were removed from both the hand-cut whole-stalk samples and from a sub sample of the billets collected from each plot. EMRE was calculated as:

$$\frac{\alpha - \beta}{\varepsilon} = \omega \qquad (1)$$

where α = EM of whole-stalk samples, β = EM of billet samples, ε = EM levels of whole-stalk samples, and ω = EMRE. The cleaned whole-stalk samples and the remaining billet samples collected from each plot were used to determine sugar quality parameters including cane Brix, cane fiber, pol, and juice sediment. Sugar loss (SL) was calculated from the mass balance results as described by Sichter et al. (2005). SL was calculated as:

$$\alpha - \beta = \omega \qquad (2)$$

where α = sugar yield of whole-stalk samples, β = sugar yield of chopper harvested samples, and ω = SL. This calculated SL was compared to the measured sugar loss from the residue samples. Data were analyzed using PROC MIXED (SAS, 2001) with ground and fan speeds as fixed variables and year and replication as random variables. Means of significant effects were separated using the PDIFF option along with the Saxton macro at $p = 0.05$ (Saxton, 1998).

Results and Discussion

Cane Yield, TRS, Sugar Yield

Statistical analysis revealed significant year by fan speed interaction, so the data was reanalyzed separately by year. Harvesting conditions are the most probable result for this interaction. In 2003, humidity was low (50%) and cane moisture was minimal, while in 2004 a 2-cm rain event occurred two days prior to harvesting the trial; humidity was high (90%) and cane moisture was non-optimal. Hurney et al. (1984) indicated that optimum fan speed varies with variety, moisture level of leaf material, and humidity level. There was no fan speed by ground speed interaction for the parameters measured in this study except for fiber in 2004.

In 2003, fan speed significantly influenced cane yield and TRS levels. The 1050 rpm setting reduced cane yields by 16.4 and 10.3 Mg ha^{-1} compared to the 650- and 850-rpm fan speeds, respectively. The 850-rpm setting reduced cane yield by 6.1 Mg ha^{-1} compared to the 650 setting. On the other hand, TRS was increased with the maximum fan setting by 14 g kg^{-1} relative to the 650-rpm speed; numerically the 1050 setting increased TRS by 7 g kg^{-1} compared to the 850 setting. The reciprocal effects of primary fan speed on cane yield and TRS counteracted each other in terms of sugar yield; sugar yields (Mg ha^{-1}) were not significantly different for the 650 (10.6), 850 (10.6), and 1050 (10.0) fan speeds.

Richard et al. (2001) reported similar findings where hand-cut samples with high EM increased tonnage, decreased TRS, and had equal sugar yield to hand-cleaned samples.

In 2004, the 1050 fan speed had a similar effect on cane yield, reducing cane yield by 12.1 and 11.9 Mg ha^{-1} compared to the 650 and 850 fan speeds, respectively. On the other hand, fan speeds did not significantly affect TRS, which was 129, 128, and 133 g kg^{-1} for the 650-, 850-, and 1050-rpm speeds, respectively. The reduction in cane yield caused by increasing fan speeds was not counterbalanced by an increase in TRS. Thus, the 1050 fan speed resulted in an average loss of 1.2 Mg ha^{-1} sugar yield relative to the two lower settings. Whiteing et al. (2001) reported that under wet conditions with older model harvesters, increases in TRS did not compensate for the excessive losses caused by high fan speeds.

Unlike fan speeds, ground speeds did not influence cane yield, TRS levels, and sugar yield for both trials. Cane yields were 94.5, 92.1, and 92.1 Mg ha^{-1} in 2003 and 88.3, 89.1, and 87.1 in 2004 for the 4.0-, 4.8-, and 5.6-km h^{-1} ground speeds, respectively. TRS levels ranged from 113 to 114 g kg^{-1} and 130 to 131 g kg^{-1} in 2003 and 2004, respectively. Sugar yields for the 4.0-, 4.8-, and 5.6-km h^{-1} speeds were respectively 10.6, 10.3, and 10.3 Mg ha^{-1} in 2003 and 11.4, 11.5, and 11.4 Mg ha^{-1} in 2004.

Field Losses

The 1050 rpm setting increased cane loss by 7.2 and 11.4 Mg ha^{-1} compared to the 850- and 650-rpm fan speeds in 2003. The 850-rpm setting increased cane loss by 4.2 Mg ha^{-1} compared to the 650 setting. Moreover, the 1050 setting had nearly twice the sugar loss (0.21 Mg ha^{-1}) compared to the 650 setting (0.11 Mg ha^{-1}) and 850 setting (0.10 Mg ha^{-1}). In 2004, the 1050 setting increased cane and sugar losses by 5.8 and 0.28 Mg ha^{-1} compared to the 650 fan speed. In 2003 and 2004, field losses in terms of sugar averaged 1.3% and 2.0% of total sugar harvested. Prior studies with older model harvesters indicated field losses of 1.5% (Richard et al., 1996).

In 2003, sugar concentration of the post-harvest residue was similar for all fan speeds, but in 2004, the residue from the high and medium settings had TRS values of 19.8 and 17.3 compared to 6.5 g kg^{-1} for the low setting. Ground speed did not affect cane or sugar loss in 2003. In 2004 the fastest ground speed resulted in post-harvest residue with significantly lower TRS levels (3.4 g kg^{-1}) compared to the other ground speeds, which produced residue with TRS values averaging 19.9 g kg^{-1}. This lower TRS value of the post-harvest residue indicates that the highest pour rate produced by the 5.6 km h^{-1} coupled with the poor harvesting conditions in 2004 caused a reduction in the cleaning capacity of the harvester.

Calculated sugar loss was higher than measured sugar loss. The measured sugar loss only accounted for 15% of the calculated sugar loss. New techniques for measuring small quantities of sugar in field residue have been tested and can account for 55% of calculated loss (Sichter et al., 2005). This new method was specifically designed for measuring sugar in post-harvest residue, while the technique we used was developed for measuring sugar in bagasse. Another improvement for the method of determining field loss would be to increase the sample size of residue collected. Differences in yield between the various treatments are not totally reflected in the field loss data; this error averaged 50% and was very inconsistent ranging from 18% to 87%. The field loss technique underestimated losses under optimal conditions in 2003 and overestimated losses under poor harvesting conditions in 2004. Besides the error associated with sugar detection, high error may be due to the small sample size for field loss. Yield was based on the entire 250-m^2 plot, while field loss was based on three 1-m^2 sub-samples of the entire plot. In an effort to increase accuracy, future studies will incorporate the technique described by Sichter et al. (2005) and will include larger sample sizes for field loss determination.

Quality Parameters

In 2003, all fan settings significantly reduced cane Brix and cane pol percentages compared to hand-cleaned samples by an average of 1.2% and 1.4%, respectively. The 1050-rpm speed increased cane Brix percentage by 0.9% relative to the 650 setting, and cane pol percentage by 0.6% and 1.2% relative to the 850 and 650 settings. Hand-cleaned cane had 1.3%, 1.9%, and 2.9% lower fiber percentages than the 1050, 850, and 650 fan speeds, respectively, while the highest fan speed reduced fiber percentage by 1.6% compared to the lowest setting. Similarly, juice sediment percentage was reduced by 12.3%, 16.6%, and 19.9% by hand cleaning compared to the 1050, 850, and 650 fan speeds, and the highest fan speed reduced juice sediment percentage by 7.6% compared to the lowest fan speed. Fernandes et al. (1977) reported that chopper harvesters produce more impurities, mainly EM and sediment as compared to hand-cut cane.

In 2004, there were no statistical differences between the four cleaning methods, but hand-cleaned cane resulted in numerically higher cane Brix and cane pol percentages. There was a significant ground speed by fan speed interaction for fiber percentage in 2004. Since harvest conditions were poor, one would expect that ground speed might have affected feeding characteristics, which could cause this interaction. Under wet conditions, cane feed is uneven causing cyclic over and under loading of the extractor chamber, which causes great cane loss due to excessive extraction of billets (Whiteing et al., 2001). At the 4.0-km h^{-1} ground speed, all four treatments had similar fiber levels. Lower ground speeds allowed even the lowest fan speed to reduce leafy trash adequately thus lowering fiber. On the other hand, at the 4.8- and 5.6-km h^{-1} ground speeds, the 650 fan speed had significantly higher fiber than all other treatments. Juice sediment percentage was increased by 19.1%, 16.6%, and 17.9% for the 650, 850, and 1050, respectively, fan speeds compared to the hand-cleaned samples. In 2003 and 2004, all ground speeds did decrease cane Brix percentage, cane pol percentage, and EMRE but increased fiber and juice sediment percentages compared to the hand-cleaned samples, but you would expect these differences between machine and hand-cut cane regardless of ground speed. In 2003, the 1050-, 850-, and 650-rpm speeds had EMRE values of 97.6%, 85.5%, and 47.5%, respectively with the highest and lowest speeds being significantly different. Legendre et al. (1999) reported EMRE values of 83% to 90% with the older model harvester under ideal conditions. In 2004, all fan speeds had similar EMRE values ranging from 51.4% to 66.6% indicating the inability to remove leafy trash under poor harvesting conditions.

Conclusion

When harvesting LCP 85-384 under optimal conditions, the 1050-rpm fan speed increased TRS by 10% but decreased cane yield by 15% compared to the two lower fan speeds resulting in similar sugar yields for all fan settings. Under poor conditions, the 1050 setting decreased cane yield by 13% without an increase in TRS, resulting in lower sugar yields than the low and medium fan settings. Similar to reports using older model machines (Whiteing et al., 2001), harvesters perform well under ideal conditions, but cleaning performance and cane quality decreases sharply under poor conditions regardless of fan speed. Challenges still exist to remove excess EM to increase TRS while not reducing cane yield. Moreover, best management practices need to be developed for both optimal and non-optimal harvesting conditions to prevent yield loss as seen with the high fan speed treatment under poor harvesting conditions.

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